Impacts of the Development of Environmental Suits on the Future of Human Spaceflight

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Trevor Stutzman
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Introduction

On July 24, 1969, more than 600 million people around the world were watching as Neil Armstrong stepped out of the lander onto the surface of the Moon. The suit he wore represented thousands of hours of work and research, and was the pinnacle of technology for that time ("Apollo Space Suit," 2013). Today, that same suit body technology is still in use (Chappell, 2017). The relative stagnation of spacesuit development is the purpose of this research, looking at how social construction of technology (SCOT) and paradigm shift are seen in this developmental cycle. In the past, many countries worked on developing spacesuit technology, but now this is shared with private industry that seeks to capitalize on the rapidly more accessible frontier of exo-atmospheric flight (Johnson, n.d.). A paradigm shift is appropriate for analysis, for a massive technological leap must be made as those in space go from highly trained astronauts to civilian professionals that may be working for a private company (Kuhn, 1970, Alpert, 2015). As space becomes more commercialized and available, technology that is protecting the safety of the user must also increase to protect every possible space worker or tourist (Torstein, 2019). Safety will be a priority in development, as well as public opinion of spaceflight and the possible return that investors see for suit development. Public opinion will affect the financial decisions of companies and governments, and play a significant role in the research of environmental suits. The ultimate goal of this paper is to analyze how spacesuit design and construction is a barrier to manned spaceflight and commercialization, looking at costs, social factors, technological advancements, and safety concerns.

Policy and Technical Analysis

The intention of this paper is to examine how the absence of a next generation spacesuit design will act as a barrier to increased space travel and commercialization. Data is sourced from technical reports from MIT and other universities, about the cutting edge of automated design and safety features for space exploration. NASA sources also comprise a large portion of the analysis, both due to the ease of searching databases, and the wealth of information that is available about every facet of the agency. Online databases such as Science Direct also provide a number of books and scholarly articles concerning spacesuit design and construction. Focusing on disasters such as Apollo 1 burning or flooding suits in space, historical case studies provide a clear look at issues in spacesuit design (Long, 2011, ESA, 2013). Ethnography will be used to provide a present and future look at spacesuit design, focusing on the routines of current astronauts and the new spacesuit designs for both private and public spaceflight companies. Finally, the third major component is going to be policy and network analysis, focusing on the regulatory side of human spaceflight, what restrictions there are on current spaceflight and what guidelines are required for a large-scale influx of civilian workers and tourists into space (Lane, n.d.). Policy and network analysis also benefits tracing the flow of money through organizations and governments, and how monetary support is an obstacle for any new production of reliable spacesuit designs.

History of Spacesuit Design

Moore's Law is an important concept to consider when looking at the technological advancement that has taken place since the early days of spaceflight. Moore's Law states that as the capability of computers increase, both the size and cost of these devices will decrease (Roser, n.d, Moore, 1998). The phenomenon known as Moore's Law is not entirely restricted to computing power, and similar advancements have been made in the field of mechanical motors, switches, and relays that have become even more powerful and versatile. In mechanical devices, advanced manufacturing means more accurate servo and brush motors and precise layering of electrical pathways onto microchips that has become commonplace. The first rockets had handmade electrical components, but now the computing power required to get to the moon is present in every single phone in use today (Madrigal, 2019). Manned missions were seen as the pinnacle of the Space Race during the Cold War, with the development of the Apollo Space Suit, often referred to as a "wearable spacecraft" (Chaikin, 2013). However, the latest iteration to this design was developed in 1975 (Chappell, 2017). The suits in use today face an increasing risk of failure, and do not incorporate the most significant improvements in mechanical systems or materials (Chappell 2017, ESA, 2013). As these multi-million-dollar suits age, they must be replaced as space becomes more available to a larger number of both public and private workers. A number of cases highlight the need for new suits, including the flooding of a suit while the astronaut was conducting extra-vehicular activity in space. The cooling system, meant to circulate water in order to maintain a livable temperature, began leaking into the air circulation system (ESA, 2013). Recently, NASA was forced to reschedule the first-all female spacewalk, since the ISS did not have enough of the proper suits onboard (Fortin, 2019). These two instances show a need for new spacesuit design, especially considering the workers that may go into space without the rigorous training current astronauts receive.

However, implementing these safety measures, which is of utmost importance to maintain public support for any type of space exploration, requires coordination and money from many industries and governments. Independent research groups that are developing the next generation of Beta cloth, mechanical counterpressure, or assisted movement devices face challenges of scientific cooperation across cultures (Gilbert, 2000). Beta cloth is fireproof and puncture resistant, and mechanical counterpressure can automatically seal holes in spacesuits, but many non-homogeneous groups are funding research. Social pressure was leveraged in the Space Race, as nationalistic feelings provided the support for government space programs. Recent successes from private companies have engaged the public, but the NASA budget is a current fraction of what it was as a percentage of total government spending (Amadeo, 2020, Budgets, n.d.). An estimated 20-billion-dollar industry by 2030, space transport is one facet of an industry that includes mining and exploration, and can help fuel the drive for new suit development, to put both workers and customers beyond the atmosphere (Sheetz, 2019). In the past, countries largely guided the discussion on spaceflight technology and integration, but now companies such as SpaceX, Boeing, Bigelow and others guide the development of technology in response to the economic goals they hope to achieve (Davenport, 2019, Markovich, 2019).

SCOT and Paradigm Shift in Spacesuit Design

The two main frameworks used to look at the intersection of the three concepts of Science, Technology, and Society will be the social construction of technology (SCOT), and the theory of a paradigm shift. SCOT is the theory that technology does not determine human action, but that human action shapes technology. This theory was initially crafted as a response to technological determinism, or that technology shapes society (Bijker, 2015). Berger and Luckmann (1966) see society as shaping reality, including the technology that is developed to fill societal desire. There are numerous case studies that show design as a result of negotiations between several social groups, such as the use of the telephone and later the internet. Fischer (1992) showed how these technologies were used to emphasize existing communication patterns, and not establish new ones. Social construction may also be used to further political or personal agendas, such as the construction of bridges that limit bus service, and therefore restrict low-income neighborhoods' access to recreational areas (Callahan, 2004). Massive construction projects, such as the Chunnel and Nile river irrigation schemes, represented society manipulating their technical expertise to achieve a goal (El-Kammash, n.d.). Societal desire is seen as driving factor for space development in the Cold War, which was not overtly beneficial, but boosted a sense of national pride and civic engagement (Johnson, n.d.).

Space suit development as a paradigm shift is the second framework that will be used in this paper. Popularized by Thomas Kuhn (1970), he believed that paradigm shifts were a fundamental change in approach or underlying assumptions, with alternating phases of standard science and revolutions. One example is Newton's theories about an invisible encompassing force called gravity, that when compared to the current paradigm of Ptolemy and Descartes, seemed wrong. However, once the accepted paradigm shifted and allowed acceptance of more theories, the Coulomb theories of electricity and magnetism gained acceptance by drawing comparisons to Newton's theories of gravity (Alexander, 2018). Critics of this theory point to the denial of an objective truth, but history has shown that as instruments and understanding improve there will be always be a jump to better models. The understanding of atoms, our own planetary movement, and the shape of our planet all represent examples of paradigm shifts in search of a more perfect truth (Bolling, 2018). The puzzle-paradigm model suggests that as one scientific question is answered, more puzzles will arise, and that an infinite number of puzzles can be answered with the arrival of new paradigms. Similarly, spacesuit design will always seek to solve every issue facing astronauts in space, and must undergo a paradigm shift from the past designs in order to protect tourists and workers in the current and future environment of space.

Spacesuits as a Barrier to Space Exploration

Spacesuit design faces the four primary obstacles of the cost of production and design, the necessary safety features that have to be implemented, the lack of social support for spacesuit design, and the technological divide that hinders development. Money is a necessary part of any scientific project, and developing agencies will incur substantial costs due to the required features for a new spacesuit design. Government budgets for space have been cut drastically since the Cold War era, and private spaceflight companies are running a deficit, even with many high-profile successes. Safety must be a priority for any design, as space is one of the most inhospitable environments known to man. Safety becomes a barrier to design when individuals going into space do not have extensive training, and safety features must compensate for lack of training. A single high-profile case of death resulting from a spacesuit malfunction could cripple space exploration, similar to fears that limit autonomous vehicles and artificial intelligence. Social support is a third factor, where constituents that do not have vested interest in spaceflight will not fight for space exploration in the governmental budget, or become investors in a private spaceflight company. Support from large social groups is vital for space exploration and spacesuit design, and must compete against pressing terrestrial issues such as global warming or medical advancements. Finally, the integration of scattered technological advances is another obstacle, as research labs and companies around the world develop technologies useful for spacesuit design. Groups developing these technologies face regulatory challenges in sharing information, the desire to keep intellectual property secret, and nationalistic divides between countries.

Cost

Cost is a major factor in the development of new spacesuit design, considering the dramatic reduction to government budgets that has not been fully supported by private industry, and the staggering cost to develop Apollo suit bodies. Many spaceflight or space related companies are not focusing on human spaceflight and instead on launching satellites into orbit, which is a viable way to make money through communications contracts. Due to the fact that there is little money to be made through the development of an environmental suit, companies are unwilling to devote research money to space exploration research, driven by the interests of their stockholders. Acting as societal groups, these investors can determine where funding for space is directed, such as Chinese firms pushing for ultra-accurate satellite positioning systems by giving funding to space tech firm Qianxun SI (Knapp, 2020). Private spaceflight companies represent a paradigm shift in the industry, which was primarily controlled by government institutions up until 2009. Now, the top three private human spaceflight companies are valued at nearly 5 times the total global space agency budget. NASA began to receive funding in 1958, quickly rising to more than 4% of the federal budget and becoming a fully funded government apparatus within 10 years (Garber, n.d.). The official goal was to place an astronaut on the moon, which as a government policy with societal support directed funds to spacesuit and spacecraft design. Once the Space Race began to slow, the NASA budget saw a quick decline, surpassed by defense spending that began to overlap with the NASA mission. No longer supported by governmental policy, the NASA budget has fallen to $21 billion. However, spaceflight companies show an upward trend with $5.8 billion raised in 2019 (Sheetz, 2020). In the appropriations bill for NASA, 45.8% of this $21 billion is directed towards human spaceflight, nearly a quarter of one percent of the federal budget (Planetary, 2019). However, the Apollo space program faced an inflation adjusted cost of $98 billion dollars, more than four times the cost of the NASA budget for the entire 2019 fiscal year (Stine, 2019). The Apollo program cost highlights how even with the public growth of spaceflight companies such as Boeing, SpaceX, and Lockheed Martin, a lack of money for human spaceflight and spacesuit design pervades the space industry. As space agency budgets stabilize worldwide, with a large contraction forecasted in 2025, the percentage of governmental civil spending on human spaceflight will also decrease, with less monetary support for the next generation of spacesuit design (Seminari, 2019)

Safety

Safety is a second major obstacle in the design of any new spacesuit body. Spacesuits are going into one of the most inhospitable environments and must protect the user against any accidental failures in addition to the inherent dangers presented by radiation or temperature. Several cases highlight the importance of designing a suit for safety, including the Apollo 1 test fire, and the more recent failure of an extravehicular cooling system aboard the International Space Station. In 1967, an Apollo command module test resulted in a massive fire engulfing the interior of the command module while it was still on the pad. Three issues were identified as contributing to the deaths, including faulty gas masks, failure of the flame-retardant system, and the lack of any emergency bolts on the exit capsule (Long, 2011). As a result, both the command module and suit had to undergo a massive redesign, and the public lost confidence in a space program that had just lost three astronauts while on the ground. Just as public support allowed governments to fund space agencies during the Space Race, this accident resulted in public questioning of the viability of space programs through Senate hearings and public backlash against the effectiveness of NASA design and oversight. This lack of oversight resulted in three deaths, millions in damages, and lessened American public support. One poll showed “more than half of respondents were opposed to the missions” (Hollingham, 2019). Further, the accident highlighted differences in opinion between engineers and administrators, and led to a change in the suit construction with the addition of a flame-resistant outer layer. A second case study shows the danger of the suit body due to age, since the most recent suit body was designed in 1975 (Chappell, 2017). A study by the European Space Agency in 2013 showed how a leak within the cooling system allowed for flooding to occur within the suit body, putting the lives of the astronaut at risk. Similar incidents result in further loss of confidence in the current state of the space program, and emphasize the need for a new environmental suit.

However, safety must not just take into account current astronauts, which in every case have undergone extensive training and have a military or government background. These astronauts are prepared for a suit failure to a degree that a tourist or civilian space worker will not be. Astronauts undergo continual health checkups, have rigorous exercise regimens, and have memorized emergency procedures for every piece of equipment prior to exiting the atmosphere (Lane, n.d., IOP, n.d.). The same standard of knowledge and preparation cannot be expected from every tourist or employee, and the environmental suit design must compensate for lack of training. Astronauts referred to the Apollo suit body as a mobile spacecraft, and it becomes even more vital that the life protection systems onboard are capable of protecting every individual. A modern environmental suit must be properly fitted to prevent injury, and be able to respond in the event of an emergency. As the public increases funding for tourism and commercial opportunities in space, increasing safety will in turn increase development time, testing periods, and cost. As the interested social groups, investors and governments will both want to see evidence of strict safety standards, and have the potential to cease support of human spaceflight efforts if those standards are not demonstrated. Regulatory agencies such as the Federal Aviation Administration (FAA), European Aviation Safety Agency (EASA), and NASA, have all published documents concerning crew training requirements, and the safety of passengers (HSF, 2019, Wong, 2010, Sgobba, 2010). Spacesuits that minimize danger are vital to both ensure the continuation of space programs, but also to limit oppressive regulations that could halt space travel and commercialization. Controversy has surrounded Tesla and Uber concerning driverless vehicles, even as studies suggest automated vehicles have a greatly reduced accident risk compared to a human driver (Kalra, 2016). High-profile accidents have led to states limiting testing and implementation which delays the timeline due to the safety concerns, all caused by public resistance to technology portrayed as unsafe (Angerholzer, 2017). American society is likely to react the same way to a similar high-profile accident involving tourists or workers in space, forcing the development of overengineered spacesuits.

Social Support

Social support is the third major factor for the development of a next generation spacesuit design, and the ultimate expansion of human spaceflight. During the Cold War, branding was used to effectively enlist the populations of the NATO and Soviet Bloc countries, gathering massive support for a costly endeavor to reach the moon. The term "Space Race" represented a competition with a tangible enemy, enabling multiple societies to construct massive space agencies and apparatus (Johnson, n.d.). Cooperation with multiple countries and across many varied groups of people was achieved by sharing the central goal of a moon landing. Contrasted to the Space Race, today there is minimal outspoken public support for government funded space programs. Due to the fact that there is currently no American based entry point to the ISS, and the dramatic reductions of the Russian space program reducing heavy lift to the ISS, support for these programs is low. Further public relations failures such as the cancellation of the first all-female spacewalk also serve as reminders of the declining state of human spaceflight (Fortin, 2019). Social support is critical, as social support in the form of money, advertising, promoting STEM education, and human capital is necessary for spacesuit design and construction. The lack of modern environmental suit protection prevents workers from heading into space, which results in lost money-making opportunities and dissuades investors wary of the startup cost of suit development.

Technology & Cooperation

A fourth challenge is the technological integration and cooperation required to build a spacesuit that is superior to the current version and allows for widespread manned spaceflight and travel. Multiple labs around the world are working on various technologies such as mechanical counterpressure, battery technology, hydraulic assistance, and artificial intelligence software that can aid the user in space. These technologies all represent great strides for the overall suit once they can be integrated, but the challenge exists in the cooperation and sharing of information. Mechanical counterpressure, which is the primary change to a future spacesuit, would allow for automated repair, and the ability to develop modular, one-size-fits-all design (McFarland, 2019). Modular design and repair completely change the suit design from the old pressurized shell, a paradigm shift to the newest stage of human spaceflight through next generation environmental suits (Hansen, 2019). Currently, there are several groups working on mechanical counterpressure in the US alone, including labs at Texas Tech, MIT, and the University of San Diego (Roger, 2018, Holschuh, 2012, Waldie, 2002). Developing different portions of the suit, these groups face the challenge of integrating their various appendages, such as the haptic gloves, forearm, and upper leg sections that these papers address. Even within the US, these groups have different testing parameters and procedure, and face challenges combining these systems.

Abroad, countries such as India are designing their own entire manned space programs, seeking to create every component within the country. The space program Gaganyaan, though representing a step forward for the Indian space program, highlights the lack of cooperation and isolation that current space programs cultivate (Bartels, 2018). Often experimenting with the cutting edge of new technology, modern government-run space programs suffer from fear of data theft or network intrusion if research data is shared across country lines. The Global Economic Crime and Fraud Survey and the National Institute of Standards and Technology (NIST) estimate that the world economy is facing an upward trend of intellectual property theft that could reach more than 6 trillion in the global economy by 2021 (PWC, 2018). NIST estimates that this intellectual property theft by companies and countries around the world is causing companies to hide research completely, as patent protections do not currently give a robust enough defense to technological theft (Ross, 2018). Distrust among government entities who risk losing the technological edge, and company losses of intellectual property restrict the free flow of information in a society that is required to integrate the next generation components of spacesuit design. Driving apart social groups to each develop an independent spacesuit without the benefit of shared research and testing capabilities results in increased development times, inferior products, and ultimately a delayed realization of the next stage of human space travel and exploration.

Research into spacesuit development faces several limitations, including the lack of data about new systems, which is limited to general releases by space agencies or speculation by popular scientific news sources. As discussed previously, advances required to build and develop new suits are on the technological edge of the companies and government entities developing them. Due to desires to hide data or designs, many of the technological advances discussed in this paper are gathered from universities and news agencies, not directly from groups developing human spaceflight. Further limitations concern the convoluted bureaucratic and regulatory agencies that monitor government and private spending on human spaceflight. Several different sources listed different estimates for spending concerning companies and various countries interested in human spaceflight, and the difficulty lies in verifying the accuracy of financial accounting from multiple sources. Regulatory concerns extend to limitations on new spaceflight, which, similar to many new technologies, has not reached a widespread consensus. Various regulatory agencies such as the FAA and EASA are in competition with internal regulations from companies like NASA and Boeing, all concerning human spaceflight, specifically protections that must be offered to a spacesuit user in the upper atmosphere (HSF, 2019). A final limitation is the time of the research and investigation period. Spacesuit design is a constantly evolving process, with new technologies and methods being discussed each day, such as the new materials developed by Superpower Inc. that can be used in spacesuit construction (Superpower, n.d.). A longer-term analysis of spacesuit design and construction impacts on human spaceflight could reveal additional factors that spacesuit design is having on the industry. With many varied research groups working on components of the next generation environmental suits, one is challenged to read and understand all the technological advancements. Past human spacesuit design is straightforward to analyze with the few basic designs that were developed and are still in use, but obstacles exist in predicting how and when the next spacesuit will be developed, especially under the lens of a paradigm shift from older designs.

Continuing research requires cataloguing possible advancements to suit design, as well as the public and private groups that are working on new designs. Becoming fully updated on future technological growth is important for any STS researcher that wishes to continue in the field of spacesuit design and impacts on human spaceflight. Further, a more accurate financial accounting of the human spaceflight sector is vital for understanding impacts as cost of suit development plays an increasingly important role in human spaceflight. Cost impacted the time and effectiveness of design, the support that it would gather from investors and the public, and what technology could be included. Understanding the monetary resources available to each player in the field of human spaceflight, such as Lockheed, Boeing, NASA, Gaganyaan, and the Chinese Manned Space Agency, would inform on the ability of these groups to develop a next generation space suit. More importantly, it would reveal the obstacle funds or lack thereof pose to next generation spacesuit design.

Conclusion

Spacesuit research faces the four barriers of cost, safety requirements, social support, and technological innovation. Past spacesuits designs have been costly to develop and produce, and with stricter budgets throughout the manned spaceflight industry spacesuits will take a significant portion of any manned spaceflight program. Safety requirements are increasingly strict, both to prevent astronaut injury and protect the next generation of spacefaring tourists and workers. Due to accidents and public relations failures, manned spaceflight does not have the social support it once did, resulting in little incentive for investors or government entities to pursue spacesuit development. Finally, integrating the technology that is being developed around the world into the next generation environmental suit poses a challenge, as intellectual property theft is an increasing deterrent to sharing of useful technological innovation on spacesuit design.

Manned spaceflight faces many barriers, including developing next generation rockets, habitable craft, and spacesuits. However, even with these obstacles, it is vital that the spacesuit functions perfectly as the last line of protection for future astronauts. Since 2009, the emergence of new options to reach space has pushed the problem of manned spaceflight to protecting individuals once they reach the upper atmosphere and deep space. The spacesuit is a necessary part of protecting space explorers, boosting tourism and commercial interests, and forming a space industry that will spread throughout the solar system.

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